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Laser-Plasma Interactions in Drive Campaign targets on the National Ignition Facility

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Abstract. The Drive campaign [D A Callahan *et al.*, this conference] on the National Ignition Facility (NIF) laser [E. I. Moses, R. N. Boyd, B. A. Remington, C. J. Keane, R. Al-Ayat, *Phys. Plasmas* **16**, 041006 (2009)] has the focused goal of understanding and optimizing the hohlraum for ignition. Both the temperature and symmetry of the radiation drive depend on laser and hohlraum characteristics. The temperature of the drive strongly depends on the coupling of laser energy to the hohlraum, and the symmetry of the drive is critically dependent on beam-to-beam interaction that result in energy transfer [P. A. Michel, S. H. Glenzer, L. Divol, *et al.*, *Phys. Plasmas* **17**, 056305 (2010).] within the hohlraum. To this end, hohlraums are being fielded where shape (rugby vs. cylindrical hohlraums), gas fill composition (neopentane at room temperature vs. cryogenic helium), and gas fill density (increase of $\sim 150\%$) are independently changed. Cylindrical hohlraums with higher gas fill density show improved inner beam propagation, as should rugby hohlraums, because of the larger radius over the capsule (7 mm vs. 5.75 mm in a cylindrical hohlraum). Improvement in energy coupling occurs in room temperature neopentane targets, as well as in hohlraums at higher gas fill density. In addition cross-beam energy transfer is being addressed directly by using targets that mock up one end of a hohlraum, but allow observation of the laser beam uniformity after energy transfer. Ideas such as splitting quads into “doublets” by re-pointing the right and left half of quads are also being pursued. LPI results of the Drive campaign will be summarized, and analyses of future directions presented

1. Introduction

The radiation environment for an indirect drive capsule at the National Ignition Facility (NIF) [1] is the hohlraum (Figure 1). A hohlraum (“empty room”) is typically a cylinder composed of high-Z material such as gold. A capsule is held in the center of the hohlraum by a tent, and is surrounded with low-Z gas, which acts to tamp the wall as it expands. Laser Entrance Holes (LEH), centered in the cylinder endcaps, are where laser beams enter the hohlraum. The beams propagate to the hohlraum wall where they are converted to x-rays, which drive the capsule implosion. The job of the hohlraum is to provide an appropriately “hot” radiation environment for the capsule implosion, and to provide sufficient radiation symmetry that the capsule remains nearly spherical as it implodes.

Laser-plasma interactions (LPI) impact both of these hohlraum aspects (“hot”, and “round”). To reduce the impact of LPI we have modified three different aspects of the hohlraum to investigate performance improvements. To improve hohlraum performance (both “hot” and “round”), we have modified the hohlraum fill composition (He replaced by C_5H_{12} , shot at room temperature), hohlraum fill gas density (increased by > 1.5 for the HiFoot design, and decreased to near-vacuum for 2-shock HDC capsules), and the hohlraum shape (cylinder to rugby) (c.f. Figure 1). In Section 2 we discuss recent progress on the impact of LPI on keeping the hohlraum “hot”. In Section 3, we present a snapshot in time of the impact of LPI on capsule implosion sphericity. In Section 4 we summarize our results.

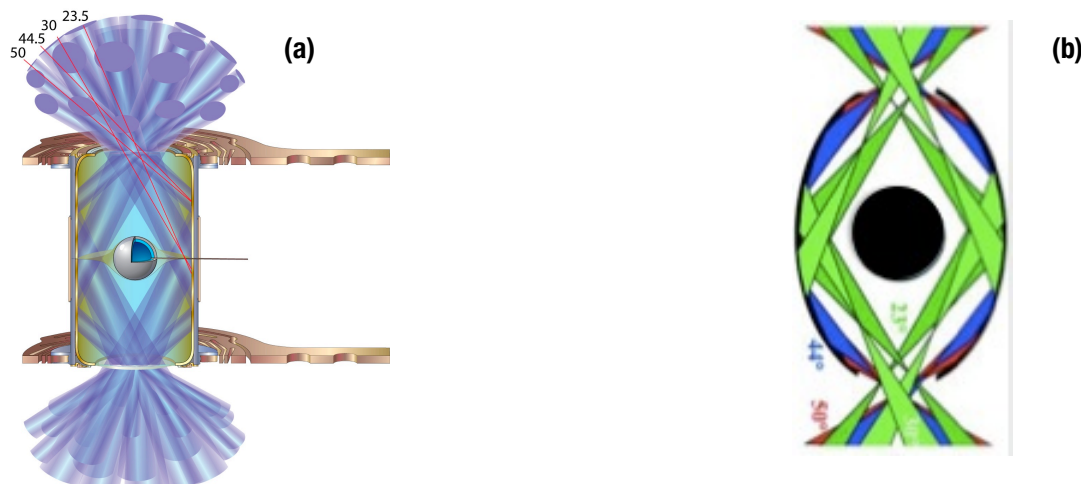


Figure 1. (a) An inertial confinement fusion (ICF) hohlraum provides a hot and symmetric radiation environment for the imploding capsule, suspended in its center. Laser-plasma interactions impact both of these aspects of the radiation environment. To keep the radiation temperature “hot”, we have modified the hohlraum gas fill composition and the hohlraum gas fill density. (b) We have also modified the hohlraum shape from cylindrical to rugby.

2. Laser-plasma interactions in NIF hohlraums

As the laser beams propagate into the hohlraum toward the wall, they interact with the plasma environment. Stimulated Raman scatter (SRS) [2] occurs when a beam resonantly scatters off self-generated electron plasma waves. Stimulated Brillouin scatter (SBS) [2] occurs when resonant scatter off self-generated ion acoustic waves occurs. Both of these processes can lead to a direct loss of laser energy coupling to the hohlraum wall, and thus a drive reduction.

The Full Aperture Backscatter Station (FABS) [3] measures light scattered out of the hohlraum back down the beam line on one 30° and one 50° quad. The Near Backscatter Imager (NBI) [3] is a plate that surrounds these two quads, collecting near-backscattered light. On one 23° quad there is a plate between the four beam lines of a quad that captures near-backscattered light. During 2011-2012, over the time when shock-timed implosions were fielded at NIF as part of the National Ignition Campaign (NIC), the measured SRS light from the 23° and 30° cones (16 quads in all) was nearly constant at ~ 150 kJ. Inner cone SBS adds approximately an additional 10-50 kJ of scattered light in the first three-quarters of 2011. In the fall of 2011, the NIC moved to a slightly larger hohlraum (5.75 mm in diameter vs 5.44 mm) which, when optimized, resulted in inner beam re-pointing. The inner cones were moved slightly outward, and thus intersect less capsule ablator material as they propagate toward the wall. The resulting inner cone SBS was subsequently reduced to 10 kJ or less.

The NIF hohlraum outer beams (44.5° and 50° cones) create a gold bubble, in which SBS predominantly occurs. In 2011 and early 2012, outer cone SBS varied from 5 to ~ 35 kJ. When the laser pulse at peak power was lengthened in March, 2012, the outer cone SBS increased to 40-50 kJ. Overall, on average, the measured FABS/NBI backscatter in the 2011-2012 timeframe suggests backscatter energies of ~ 200 kJ.

The laser drive diagnostic (DrD) provides an alternate measure of SBS. Here, a grating on the output of the main debris shield provides a diagnostic beam sample of the input beam ($\sim 0.1\%$). SBS from the hohlraum that propagates back down a beam line reflects off the second harmonic crystal at the 4% level, and is detected by the DrD. NIF DrDs have measured SBS back up 57 of 192 beam lines since 2009. Data analysis (P. A. Michel and B. J. MacGowan, [4]) shows that the DrD data correlates with FABS measurements. Further, variations in the detected SBS correlates with hohlraum perturbations such as diagnostic windows (beams striking the diagnostic windows show different SBS levels). There are also SBS variations that correlate with the topology of cross-beam energy transfer [5]. For example, a dropped quad will result in modified power transfer to other quads, and thus different SBS levels. Further, DrD measurements indicate lower SBS on the 44° beams than on the 50° beams.

Within the last year, we have modified the hohlraum to investigate performance improvements, with the goals of: (i) increasing the electron temperature within the hohlraum, and thereby reducing backscatter; (ii) reducing hohlraum wall motion, thereby improving inner beam propagation; (iii) fielding a hohlraum that provides sufficient radiation symmetry without cross-beam energy transfer.

With respect to (i) above, we have modified the hohlraum gas fill composition. To show efficacy, we fielded room temperature hohlraums with a neopentane gas fill. This fill, when ionized, has a larger effective Z , and thus inverse bremsstrahlung of the laser light increases, thereby increasing the electron temperature. In Figure 2, the nominal hohlraum has ~ 150 kJ of SRS and ~ 20 kJ of SBS (labelled He low foot). The SRS is reduced to ~ 60 kJ when the gas fill is changed to neopentane. However, the SBS on the outer beams increases to ~ 65 kJ. This SBS increase can be mitigated by borating the gold wall, thereby increasing ion Landau damping. This is a promising avenue for reducing backscatter losses.

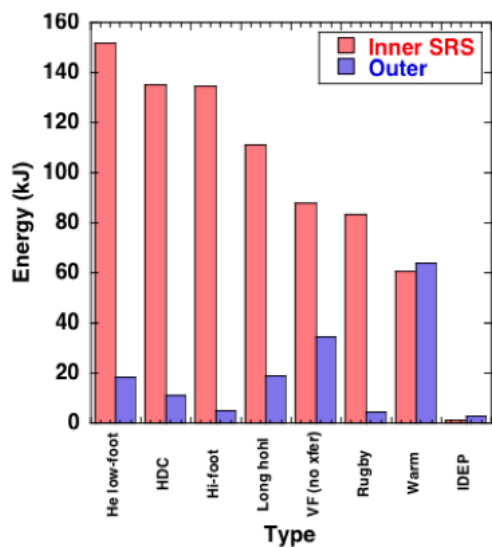


Figure 2. A plot of backscattered energy vs hohlraum modification. Red depicts SRS levels, blue depicts SBS levels.

To address (ii) above, we have fielded hohlraums where we have varied the gas fill density. In hohlraums where the capsule has an HDC ablator or a high foot drive, the gas fill density is increased. Here, both SRS and SBS are decreased from that in the nominal low foot hohlraum. Further we have also fielded the Indirect Drive Exploding Pusher (IDEP), a near vacuum target with very low gas fill density. This target demonstrated $\sim 99\%$ laser energy coupling, where both SRS and SBS were significantly decreased.

Finally, we modified the hohlraum shape (iii) from cylinder to “rugby”. Here the inner beam SRS levels decreased by nearly a factor of two, and outer beam SBS levels were lower than in the nominal hohlraum. The backscatter levels in this target, where cross-beam energy transfer was not used are quite similar to a

cylindrical target without any cross-beam transfer [labelled as VF (no xfer)]. Future studies will continue to research items (i)-(iii).

3. Radiation symmetry in NIF hohlraums

NIF routinely uses cross-beam energy transfer (CBET) to achieve time-integrated P2 symmetry, i.e., to mitigate the tendency of the central hotspot to be oblate. CBET occurs where laser beams overlap, predominantly in the laser entrance holes. At NIF, the outer beams are incident on the hohlraum at a wavelength $\lambda_0 - \Delta\lambda$, and the inner beams at a wavelength of λ_0 . Forward Brillouin scatter transfers energy from the outer to the inner beams, which have a more difficult time reaching the wall because of their longer path length through cooler plasma. Since CBET scales as $I n_e / T_e$, where I is the laser intensity, n_e is the electron plasma density, and T_e is the electron temperature, it most readily occurs during the early part of the laser pulse (when T_e is low) and at peak power, when the laser intensity is high. Simulations of CBET predict that the laser beams are spatially non-uniform, and thus this process is introducing a spatio-temporal intensity distribution. To assess the impact of these non-uniformities, we have changed the hohlraum shape from cylinder to rugby. The rugby shape allows for inner beam propagation without CBET. In May, 2013, we shot a rugby at full energy (1.3 MJ) and power (380 TW). This hohlraum showed good laser energy coupling (93%), but poor inner beam propagation. Experimental diagnostics suggest significant wall motion, which impedes inner beam propagation. Our next rugby hohlraum will be shot with modified outer beam pointing (move inward by 500 μm), which is predicted to improve the radiation symmetry without using CBET.

The room temperature hohlraums with neopentane gas fill did not only show better energy coupling (as discussed in Section 2), but also achieved decent radiation symmetry at lower levels of CBET (smaller $\Delta\lambda$ difference between inner and outer beams). The challenge here is to field a cryogenic hohlraum with higher-Z fill. To this end, we plan to shoot a rugby hohlraum with 2.45 % atomic fraction neon in the helium gas fill, which will not freeze out at cryogenic temperatures.

4. Summary

We have investigated hohlraum performance improvements by modifying hohlraum shape as well as gas fill density and composition. The challenge here is to optimize across shape, fill composition, and fill density to find an optimized hohlraum with reduced backscatter losses, with minimal cross-beam energy transfer, and with good radiation symmetry. Rugby hohlraums hold promise for achieving radiation symmetry without large levels of cross-beam transfer. We plan to investigate other shapes, and to research different strategies for increasing the electron temperature within the hohlraum, as well as to perform a scan in gas fill density.

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